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HUMAN PERFORMANCE AS A FUNCTION OF CHANGES IN ACOUSTIC NOISE LEVELS

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AEROSPACE MEDICAL RESEARCH LABORATORIES
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Foreword

This study was conducted in the Environmental Stress Branch, Training Research Division, Behavioral Sciences Laboratory of the Aerospace Medical Research Laboratories, under Project 1710, "Training, Personnel, and Psychological Stress Aspects of Bioastronautics," Task 171002, "Performance Effects of Environmental Stress." The study was initiated in June 1964 and completed in February 1965.

The authors are indebted to Mr. Henry C. Sommer, Biological Acoustics Branch, for calibration and spectral analysis of the noise levels used in the experiment.

This technical report has been reviewed and is approved.

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Abstract

Psychomotor performance of 16 subjects was evaluated under four noise conditions, during four test sessions, in a Latin square design. Three experimental conditions each began with different intensities of noise (*Quiet*, 85 dB, or 95 dB). After 30 minutes exposure the noise was changed to a final high intensity level (110 dB), which lasted for 15 minutes. The fourth condition served as a control, in which *Quiet* prevailed throughout the entire 45 minute period. The results partially supported the hypothesis that greater changes in noise levels produce greater decrements in performance. There was, however, a strong interaction between noise conditions and sessions. The nature of this interaction indicated that this phenomenon does not occur uniformly throughout the course of learning, and probably is of lesser importance for well learned tasks.

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SECTION I

Introduction

Advances in the field of protective equipment have kept pace fairly well with technological advances in weapons systems, aerodynamic designs, and new sources of power, which have subjected man to ever increasing stresses. However, to effectively fulfill his mission and realize his potential usefulness in such advanced systems, man must do more than merely survive the rigors of a hostile environment. He must be able to perform certain tasks accurately and within specified time limits during exposure to a number of different stresses, as well as after such exposure. Therefore, to realistically assess what can be expected of a man in these kinds of situations, we must have information about effects produced on human performance by levels of environmental stresses that are below those which are physiologically damaging.

One such stress present in many military systems is noise. Sound pressure levels above about 135 dB* produce pain, and if exposures at this level are for any appreciable length of time, permanent physiological damage will be sustained. Sufficiently prolonged exposure at lower levels, in the 95 to 130 dB range, will cause permanent hearing losses even though such exposures may not be accompanied by pain. Therefore, personnel working in high-energy sound fields are required to wear protective devices, or limit the durations of their exposure, or both. Nevertheless, it is often impossible, or at least impractical, to reduce noise levels beyond a certain point, and as a result men must often perform complicated and demanding tasks at fairly high intensity, effective noise levels. It becomes important then to know just what effect noise has on the performance of such tasks.

Perhaps the only conclusion one can reach from reading reviews of the effects of noise on human performance (refs 3, 14, 15) is that there are effects. Whether these effects are detrimental or facilitative (or both), how they are related to intensity, what changes occur over time, etc., remain largely undetermined. Several studies (refs 4, 9, 19), do show that high intensity noise conditions (100-115 dB) produce decrements relative to low intensity noise or *Quiet* conditions (80 dB or less) on tasks which are repetitive, demanding, and prolonged.

Broadbent (ref 4) contends that there were several factors that enabled him to demonstrate a decrement in performance while many other similar experiments produced mainly negative results. He states that these factors are: task difficulty, individual differences, measurement of prolonged performance, and use of analytical scores. Some of these factors also appeared to play a part in demonstrating significant decrements in the experiments by Jerison (ref 9) and Wilkinson (ref 19).

Evidence on the relationship between noise level and degree of performance decrement suggests that the higher the intensity, the greater the decrement. Reasoning from the effects of other stresses, this is certainly the sort of relationship one would expect. However, there is a fair amount of evidence indicating that the relationship may be considerably more complex than this – at least where temporal combinations of different noise levels are involved. In other words when a situation involves noise levels that are changing and becoming either more or less intense,

*All intensity values in this report are given in decibles of sound pressure, re 0.0002 dynes/cm^2.

which is true of many real situations, the important variable may be the change rather than the absolute noise levels involved. This concept is far from being unknown or new. Studies by Morgan (ref 12) and Ford (ref 7) showed that the removal of a noise produced decrements similar to those produced by its introduction. Azrin (ref 2) reports parallel effects on a conditioned response to a fixed-interval reinforcement schedule. In a recent article, Teichner, Arees and Reilly (ref 17) compared the effects of noise levels which changed in intensity by various fixed amounts, rather than using the simpler presence or absence of noise paradigm mentioned above.

Teichner *et al* (ref 17) required their subjects to inspect 200 consecutive sets of 10 letters each and to report which one of five previously learned three letter combinations was included in each one. During the first 150 sets each group of subjects listened to 81 dB white noise. During the last 50 sets each of the four experimental groups was exposed to one of four noise levels: 57, 69, 93, or 105 dB; and the control group continued to listen to 81 dB noise. Since the task was subject paced, errors proved to be negligible. The critical measure was the time interval from the appearance of a set of letters until the subject made his decision as to which one of the five key combinations was present. Their results showed that shifts from the 81 dB noise level to the lower levels produced decrements as great as the shifts to the higher levels, and that the degree of decrement was directly related to the absolute magnitude of the change. More precisely, what was shown was a deceleration in the rate of improvement on the task, which represented a decrement in performance relative to the control group, rather than an absolute decrement. Nevertheless, if this phenomenon should be found to generalize to well-learned tasks, the practical implications of such a result would be of considerable importance.

To digress for a moment to a more abstract level, such findings also appear important from a theoretical frame of reference. That is, they lend support to recent discussions concerning the possibility that the reticular formation takes on an adaptation level based on contextual stimulation, and that any sudden increase or decrease in stimulation may produce behavioral aberrations (ref 11, p. 176). Theorizations of this nature usually involve the concepts of sensory overload and sensory deprivation. However, it would appear that these concepts would have to be defined in a relative way, dependent upon a particular adaptation level.

Returning to the Teichner study, although the changes in performance which are reported seem substantial, unfortunately no test of their statistical significance is included. This fact, coupled with the previously mentioned relative nature of the decrements which were observed, prompted the present investigation. It was reasoned that an experiment similar to the one by Teichner *et al*, but not identical with it, would serve as a test of the validity and generality of their findings, and also be of practical as well as theoretical importance.

While the present experiment is analogous to the Teichner study, it differs from it in a number of significant ways. Many of these differences will become apparent from reading the method section which follows. Others will be mentioned specifically in the discussion. In general, the experiment was a comparison of four noise conditions. The three experimental conditions each began with different intensities (*Quiet*, 85 dB, or 95 dB). After 30 minutes they were switched to a final, high intensity level (110 dB) for 15 minutes. The fourth condition served as a control, in which *Quiet* prevailed throughout the entire 45 minute period. The specific hypothesis to be examined was that the greater the magnitude of the change in intensity, the greater will be the decrement produced.

SECTION II

Method

Subjects

Sixteen male university students served as subjects. They were paid volunteers and ranged in age from 17 to 22 years with a mean age of 19.5 years.

Noise Source

The output of a General Radio random-noise generator (Type 1390-A) was recorded, using a Wollensak Model T-1500 tape recorder. The same recorder was used to play back the noise to the subjects through earphones (R.C.A. H-79AIC). Noise levels were determined by attaching the earphone to a Bruel and Kjaer artificial ear, using a 6 cc coupler. The output from the artificial ear was then amplified, using a Bruel and Kjaer power supply and amplifier, passed through a Gersth band-pass filter, and then fed to a Ballentine vacuum tube voltmeter, from which the sound pressure levels were read. Three noise levels determined in this manner were used: 85 dB, 95 dB, and 110 dB. A spectral analysis by octave bands of the 95 dB noise is presented in table I. The spectra of the other levels were approximately the same shape. A fourth noise level, or *Quiet* condition, was simply the ambient noise in the experimental room (approximately 65 dB) atteunated by the earphones.

TABLE I

SPECTRAL ANALYSIS OF 95-DECIBEL NOISE

Octave Band (cps)	*dB*
Overall	95
150-300	55
300-600	72
600-1200	71
1200-2400	88
2400-4800	82
4800-9600	90

Performance Measure

Performance was measured by means of the Tsai-Partington Numbers Test (ref 1). Work by Tsai, using an earlier form of the test, showed that it was related to pilot washout rate in the Chinese Air Force and to scores on a United States Army test for truck drivers (ref 1). Eysenck and Willett (ref 6) have demonstrated that high-drive groups score lower on the Tsai-Partington than low-drive groups, and they have hypothesized a reduction in cue utilization as the causative factor.

This test, as described by Ammons (ref 1), consists of a booklet, each page of which has a series of numbers from 1 through 25 randomly located over the entire sheet. The number 1 is always located in the center of each page and the subject's task is to draw a line from 1 to 2 to 3, and so on, through as many numbers as he can during a specified time interval. His score is the last number in the series through which the line has been correctly drawn, with omitted or incorrect numbers being counted as errors and subtracted.

Thirty different pages, of the type described above, were constructed and duplicated. From these a 30-page training form, and two 75-page test forms were assembled. In test form A pages 1-15 appeared three times each, and pages 16-30 appeared twice; while in form B pages 16-30 appeared three times, and pages 1-15 appeared twice. The order of the pages was different for each of the two forms.

Thirty seconds of working time were allowed for each page, with a 6-second interval between pages. Start and stop signals were given by means of an electric timer which caused a red light to illuminate the subject's test booklet during the intertrial interval. At the beginning of a session the timer was started and when the red light went out the subject opened the booklet and began working. At the end of 30 seconds the light came on again signalling him to stop. Six seconds later the red light went out again and he turned the page and began working on the second page, and so on through the entire booklet.

Experimental Design

Four noise levels were used in this experiment: 85 dB, 95 dB, 110 dB, and a *Quiet* condition. These four levels were temporally combined to form the four experimental conditions shown in table II. The experimental design was a counterbalanced treatment by subject's design, in which each subject took all four treatments in one of four counterbalanced orders. Table III indicates the four orders in which the noise conditions were given. Each order was administered to four subjects.

Before the beginning of session 1 each subject was given a training session in which he completed the 30-page training booklet without any of the noise conditions. Following this the experimenter examined the training booklet to be sure that the task was being performed correctly. Then the subject was given either form A or B of the test booklet, which he worked for 45 minutes while being exposed to one of the noise conditions. At the completion of session 1 he was given a break of approximately 75 minutes, and then given the alternate form of the test booklet and exposed to a second noise condition during session 2. Sessions 3 and 4 were conducted in the same manner either on the following day or the day after. Half the subjects were tested during the morning and half were tested during the afternoon. In addition, half the subjects were given the test booklets in an AB-BA order, while the other half received them in a BA-AB order. Each booklet order was paired with each treatment order an equal number of times, and each treatment order was given an equal number of times in the morning and in the afternoon.

TABLE II

EXPERIMENTAL CONDITIONS

Condition	*Initial Noise Level* *30 min*	*Final Noise Level* *15 min*
I	*Quiet*	110 dB
II	85 dB	110 dB
III	95 dB	110 dB
IV (Control)	*Quiet*	*Quiet*

TABLE III

COUNTERBALANCING OF NOISE CONDITIONS

	Sessions			
Order	*1*	*2*	*3*	*4*
A	I	II	III	IV
B	III	I	IV	II
C	II	IV	I	III
D	IV	III	II	I

SECTION III

Results

Ammons, in her article on the Tsai-Partington (ref 1), reported that almost no learning occurred over ten trials when a massed trials presentation was used, although considerable learning was evidenced during distributed presentation with 1-minute intertrial intervals. Since the 6-second intertrial interval used in the present study closely approximated a massed presentation, it was anticipated that the 30-trial training session would bring the subjects up to a performance level close to maximum, and minimize learning as a factor in the experiment. The data revealed that this was not the case and that average performance improved within sessions from trial 1 through trial 75, as well as from session 1 through session 4. The learning between sessions, as well as part of the within sessions improvement, may have resulted because the 30 different pages were repeated, providing an opportunity for certain unique patterns of numbers to be recalled (a condition which did not exist in Ammons' study). A large part of the within sessions learning may have been due to a "warm up" effect, since the improvement was most pronounced in the early trials. In view of this finding, the scores for trials 1-25 were excluded from the analyses which follow.

Figure 1 presents the means for the four noise conditions for trials 26-50 (before the noise change) as open circles, and for trials 51-75 (after the noise change) as filled circles. An inspection of the means for trials 26-50 suggests that the initial noise levels of 85 dB and 95 dB had a small facilitative effect in comparison to the other two conditions, which both began with *Quiet*. To test the significance of this effect an analysis of variance (ref 10) was run using the means of trials 26-50 for each subject during each noise condition as the basic data. This analysis revealed no significant effects due to the noise conditions, and the only significant F-ratio obtained was for sessions ($p<.001$). This result is shown as the broken line in figure 2.

Returning to figure 1, from the observed means for trials 51-75, performance during the 110 dB noise following 85 dB or 95 dB appears to be comparable to performance in the control condition during the equivalent time period. However, performance during 110 dB following *Quiet* seems inferior. To statistically evaluate this result, a second analysis of variance was performed, using the data from trials 51-75. Again the apparent effect of the noise conditions was not statistically significant, and again the only significant F was for sessions ($p<.001$). This result is shown by the solid line in figure 2.

To evaluate performance after the noise change relative to performance before the noise change, a third analysis of variance was performed. This analysis was based on the difference scores obtained by subtracting the average for trials 26-50 from the average for trials 51-75. The results are shown in table IV. The difference scores also revealed a significant effect for sessions, but at a lowered level of confidence ($p<.05$). In addition, the interaction between noise conditions and sessions was found to be highly significant ($p<.001$). The interaction table revealed that the interaction was heterogeneous and very difficult to interpret. Therefore, analyses were made of the simple effects of the noise conditions for each session. This resulted in a significant F only in session 2 (see table V). Table VI presents the means for each noise condition during session 2, as well as the differences between the means. Table VI shows that conditions I and II resulted in significantly poorer performance than conditions III and IV, during session 2.

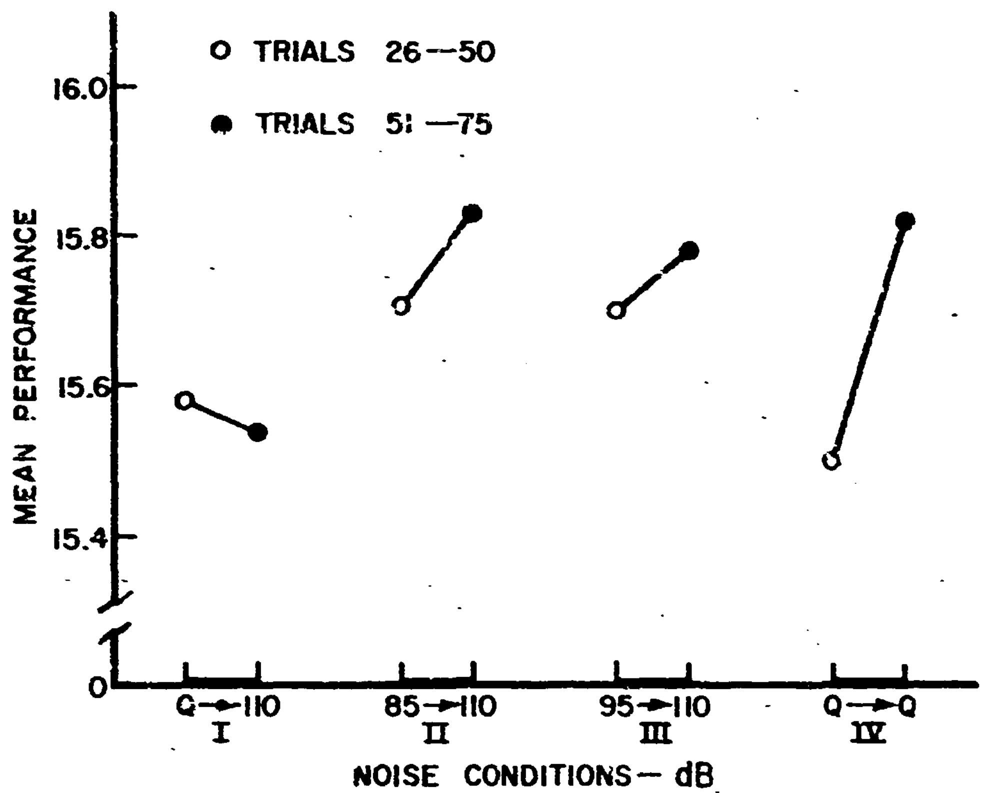

Figure 1. Mean Performance for Each Noise Condition for Trials 26-50 (Initial Noise Level) and Trials 51-75 (Final Noise Level).

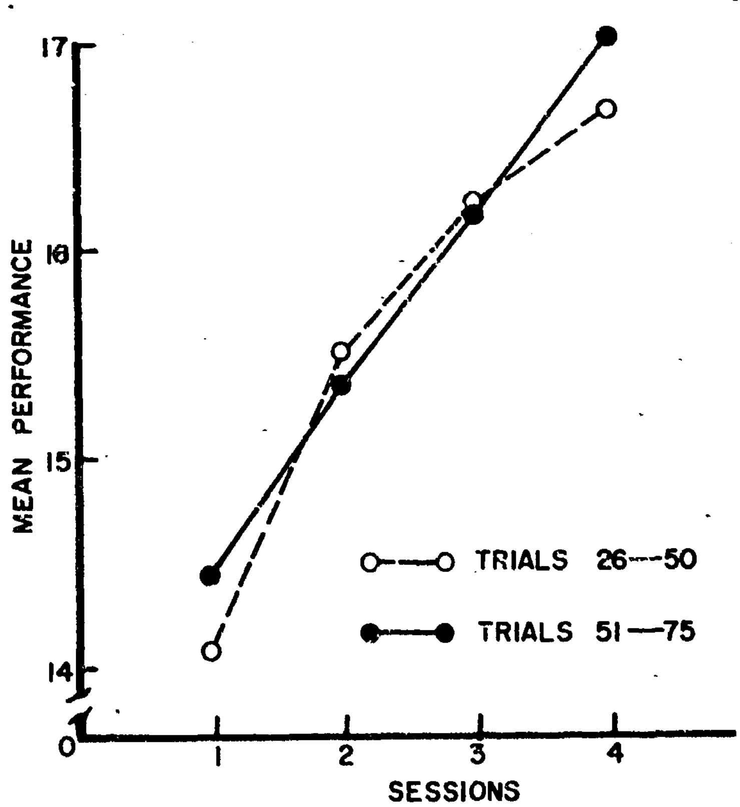

Figure 2. Mean Performance for Each Session for Trials 26-50 and Trials 51-75.

In addition to the analysis of variance, an L test was applied to the difference scores (ref 13), to directly test the monotonic hypothesis that greater changes in noise levels produce greater decrements in performance. L is a nonparametric test for linear ranks, which was developed specifically to test ordered hypotheses. The value of L obtained was significant at the .05 level.

TABLE IV

SUMMARY OF ANALYSIS OF VARIANCE FOR DIFFERENCE SCORES

Source	*df*	*Sums of Squares*	*Mean Squares*	*F*	*p*
Between Subjects	15	10.0967			
AB (b) (Orders)	3	3.1305	1.0435	1.80	NS
error (b)	12	6.9662	.5805		
Within Subjects	48	24.1304			
A (Noise Cond.)	3	1.0785	.3595	1.22	NS
B (Sessions)	3	3.1201	1.0400	3.53	$<.05$
AB (w)	6	9.3262	1.5544	5.28	$<.001$
error (w)	36	10.6056	.2946		
Total	63	34.2271			

TABLE V

SUMMARY OF ANALYSIS OF VARIANCE OF SIMPLE EFFECTS OF NOISE CONDITIONS FOR SESSION 2 (DIFFERENCE SCORES)

Source	*df*	*Sums of Squares*	*Mean Squares*	*F*	*p*
Between Conditions	3	3.1715	1.0572	3.53	$<.05$
Within Conditions	12	3.5908	.2992		
Total	15	6.7623			

TABLE VI

MEANS AND DIFFERENCES BETWEEN MEANS OF NOISE CONDITIONS FOR SESSION 2 (DIFFERENCE SCORES)

Conditions	*Means*	*I*	*II*	*III*	*IV*
I (*Quiet*- 110)	−.56		.07	.79*	.91**
II (85 - 110)	−.63			.86**	.93**
III (95 - 110)	+.23				.12
IV (*Quiet-Quiet*)	+.35				

*Sig beyond .10 level } (*t*-test)
**Sig beyond .05 level }

SECTION IV

Discussion

Perhaps the most consistent finding in this study was the significant effect due to sessions. For the means of trials 26-50 and 51-75, considered separately, this simply reflected an improvement in performance from session 1 through session 4, or a typical learning effect. The sessions effect for the difference scores, however, is more complex. It is represented in figure 2 by the vertical distance between the open and filled circles for each session. As the figure indicates, during sessions 1 and 4 there was an improvement from trials 26-50 to trials 51-75, while during sessions 2 and 3 there was a small decrement. The improvements in sessions 1 and 4 probably represent early learning in the case of session 1 and an end effect during session 4. This is certainly a plausible explanation for the average effect of sessions over all noise conditions; but, of course, it is not an appropriate interpretation of sessions effects for individual noise conditions, in view of the significant interaction.

In evaluating the simple effects of the noise conditions for each session the results showed that there was a significant effect only during session 2 (table V), and the *Quiet*-110 and 85-110 noise conditions produced significantly poorer performance than the 95-110 and *Quiet-Quiet* conditions (table VI). From these results it would appear that there is partial support for the original hypothesis. At least there is an indication that during session 2 greater changes in noise levels produced greater decrements in performance. Of course these findings do not carry the same degree of reliability as would be associated with a significant main effect for noise conditions, since the analysis for simple effects becomes a simple randomized design with only four subjects represented in each treatment cell.

Although the F-test for the main effects of the noise conditions was not significant, this can be accounted for, in part, by the strong heterogeneous interaction which was present between noise conditions and sessions. Also, consider the fact, which is becoming increasingly apparent in stress research (ref 8, p. 28, ref 18), that while a stressor may have one effect on some subjects it often has a different and even opposite effect on others. Since the F-test takes into account not only the direction of an observed effect for each subject, but also its magnitude, it is possible for the averaged effect over all subjects to be practically nil, even when a preponderance of them show changes in the same direction. Further, F is a test of the null hypothesis of no differences due to the treatments, not a direct test of the ordered hypothesis with which we began. Parametric techniques for "trend analysis" do exist, but they involve restrictive assumptions which are often difficult to meet (e.g., equal intervals between treatments along some dimension).

A relatively new nonparametric statistic called L (ref 13), was specially designed to test for monotonicity in the effects of multiple treatments. It is a significance test for linear ranks which overcomes most of the difficulties mentioned in the preceding paragraph. The L-test was applied to rankings based on the difference scores obtained for the noise conditions in the present experiment. The resulting value of L was found to be significant at the .05 level of confidence. The meaning of the significant L is that there is significant agreement between the hypothesized order of treatment effects and the observed order of treatment effects. Thus in this result there is some additional support for the original hypothesis.

A reasonable conclusion, based on a consideration of all of the results, seems to be that the data show additional evidence for the phenomenon reported by Teichner *et al.* However, the decrements involved were again largely relative; and the interactions observed in the analysis of variance plus the simple effects of the noise conditions, evaluated by sessions, indicate that this phenomenon does not occur uniformly throughout the course of learning. It seems probable, from the nature of the interaction, that the effects of changing noise levels on extremely well-learned tasks would be less pronounced. This interpretation is consistent with other findings concerning the differential effects of stress at different points in learning (refs 5, 16). The present task was chosen with the expectation that performance would asymptote quickly and the effects of learning would therefore not present a problem. It is obvious from the results that this did not happen.

The design of the present experiment relates to those conditions in the Teichner study in which the noise levels increased. However, their experimental conditions changed from a common initial level to various higher ones, while ours changed from various initial levels to a common higher one. In spite of the somewhat restrictive interpretation set forth in the preceding paragraph, the similarity of results in the two studies suggests that a true phenomenon has been observed, at least where changes are from lower to higher levels. Additional research, in which various initial levels are changed to a common lower one, would be necessary to verify an ordered relationship between the magnitudes of reductions in noise level and resulting performance decrements.

As previously mentioned in the introduction, results of the nature reported here seem to be of theoretical importance with regard to the influence of prevailing stimulation levels on the reticular activating system. In interpreting the practical significance of our results, however, we must consider the absolute size of decrements produced by the noise conditions, in addition to whether or not these decrements show statistical significance. It is evident from figure 1 that the difference observed between the worst performance and the best performance is very small. In view of this we are forced to conclude that the practical importance of the particular phenomenon which we have observed may not be very great. Nevertheless, it would be premature to conclude that all effects involved with changing noise levels are so slight as to be unimportant. For example, if the task to be performed were of a nature that involved reasoning, problem solving, or other higher mental functions, entirely different results might be produced. This assumes, of course, that such tasks may be more susceptible to interference from noise. Another situation might involve more prolonged exposure to the initial noise levels, which could bring the factor of fatigue more strongly into play and perhaps result in a considerably different outcome. Additional examples of situations in which changing noise levels might produce still different results could be cited; however, those mentioned above seem sufficient to illustrate the point.

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13. ABSTRACT

Psychomotor performance of 16 subjects was evaluated under four noise conditions, during four test sessions, in a Latin square design. Three experimental conditions each began with different intensities of noise (Quiet, 85 dB, or 95 dB). After 30 minutes exposure the noise was changed to a final high intensity level (110 dB), which lasted for 15 minutes. The fourth condition served as a control, in which Quiet prevailed throughout the entire 45 minute period. The results partially supported the hypothesis that greater changes in noise levels produce greater decrements in performance. There was, however, a strong interaction between noise conditions and sessions. The nature of this interaction indicated that this phenomenon does not occur uniformly throughout the course of learning, and probably is of lesser importance for well learned tasks.

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